Analysis of Alternative Recycling Practices for TCSWD

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Submitted to—

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Executive Summary

Glass recycling has become a sustainability issue in solid waste management practices across the globe. While glass is highly recyclable in principle, current recycling practices often make glass recycling too expensive to justify. As a result, many waste-management districts have decided to cease accepting glass in their recycling programs, causing massive quantities of recyclable glass to be dumped into landfills.

Our team was tasked with finding a solution for glass recycling at the Tippecanoe County Solid Waste District (TCSWD) that is both environmentally and economically sustainable while maintaining a reasonable level of practicality. TCSWD currently accepts waste glass mixed in with other recyclable materials, which it ships to a Materials Recovery Facility (MRF) in Indianapolis for cleaning and separation. This process is very expensive for TCSWD, so they are looking for an alternative that saves them money. Currently, four solutions have been identified for glass recycling at TCSWD:

- Continue operations as usual (single-stream recycling)
- Accept glass separate from other recyclables (separate-stream recycling)
- Purchase a glass pulverizer for production of pulverized glass aggregate (PGA) onsite
- Stop accepting glass in the recycling program (landfill)

For each of these solutions we have constructed an economic balance such that we can compare the upfront costs, long term costs, and relative payoff of each alternative. We are getting this information from data provided to us by Amy Krzton-Presson from TCSWD, other recycling districts, involved entities, and external research. We also aim to quantify the environmental impact of each alternative to be included in our comparison-analysis. The environmental impact analysis is primarily based on external research, and thus is more generalized than the economic analysis. It focuses on the carbon footprint and embodied energy involved in each of the glass recycling alternatives. We also discuss social and practical considerations concerning the implementation of each of these alternatives. Based on the results of our analyses, our team recommends a switch toward separated glass recycling due to its low long-term cost and improved efficiency.

I. Background

Glass has many possible uses after it reaches the end of its product cycle. It can be reused in a wide variety of applications or it can be recycled to form new glass products. Glass can be reused as a replacement for sand in many developments. This is due to its similar chemical composition to sand and its inert qualities (18). Examples of applications in which pulverized glass aggregate (PGA) can replace sand are road fill base, asphalt, and concrete (19). Glass is also 100% recyclable, meaning it can go from a waste product back into the production cycle to form the original product indefinitely. Additionally, utilizing recycled glass in new glass production reduces the energy requirements and carbon emissions of the process (1).

The Tippecanoe County Solid Waste District (TCSWD) accepts recyclable materials from Lafayette, West Lafayette, and Purdue University. Materials from the cities are collected via two methods: curbside pickup and four drop-off sites. All materials are transported to the Lafayette Transfer Station where they are collected and eventually hauled to a materials recovery facility (MRF) in Indianapolis. TCSWD operates using a single-stream recycling model where glass is collected mixed with other recyclable materials. As a result, recycled glass from TCSWD is often highly contaminated and must be sent to a specialized glass cleaning facility in Chicago once it is sorted at the MRF. Figure 3 shows the area serving curbside pickup along with the locations of the drop-off sites and transfer station (northwest drop-off bin) (3).

Assisting us with our project is Amy Krzton-Presson, an employee of TCSWD. Amy has provided us with many of the stepping stones for getting our project on track. She has provided us with a detailed background on the function of the recycling district and proposed the four design alternatives to be analyzed in this project. Additionally, she has served as a great resource for getting in touch with affiliated parties and other government entities. It is important to note that Amy's jurisdiction is limited to the operation of the drop-off sites, and thus does not cover curbside pickup or recycling from Purdue.

II. Statement of Problem

This group seeks to take on the challenge of glass recycling. Glass recycling has become a problem in many counties, as there are significant issues in the recycling process that make recycling glass inefficient and unprofitable, removing its utility as an environmentally sustainable alternative for glass disposal.

Currently, many recycling districts utilize a single-stream recycling model. This means recyclable materials of multiple types (plastics, glass, aluminum, paper) are collected mixed together. Contamination in single stream recycling, primarily driven by improper disposal by consumers, causes a reduction in quality of the recycled material. This reduction of quality lowers the economic value of the recycled material, and if it gets low enough it gets thrown in a landfill, negating any potential environmental benefit from recycling. The mixed nature of single-stream recycling also requires that the materials be sent to a specialized materials recovery facility (MRF) to extract and sort the different types of recycled materials. Further, contaminated glass must undergo an additional cleaning process at a specialized facility in order for it to meet quality standards for recycling. Such specialized facilities are often found in major cities, requiring long-distance transportation of glass from smaller recycling districts. Glass is a very heavy material which further exacerbates the costs and emissions related to single-stream recycling.

These challenges are present in TCSWD's single-stream recycling program. The district pays hefty hauling costs to ship its mixed materials to the MRF in Indianapolis, from which it acquires no revenue. Thus, recycling glass is purely an expense for TCSWD. The long process through which the contaminated glass must endure before it is ready to be recycled also carries negative environmental impacts. These challenges are detrimental to the practicality of the recycling program, and brings to question whether TCSWD should continue to recycle glass.

III. Design Objectives

Tippecanoe County is in need of a sustainable recycling program in order to justify its continued acceptance of glass in the program. The objective for this project is to develop a solution for glass recycling at TCSWD that is sustainable:

- From an <u>economic</u> perspective
- From an <u>environmental</u> perspective
- From a <u>practical</u> and <u>social</u> perspective

We are looking to find an economically viable solution for glass disposal at TCSWD. The practicality of any recycling program is strongly associated with its profitability. TCSWD is a government entity and thus relies on government funds which come from tax-payer dollars. If tax-payers do not believe their funds are being used to their best extent, they may elect officials who will decrease funding to such programs. TCSWD needs to establish a glass recycling program that requires minimum funding from the government. Key parameters related to economical glass recycling are as follows: the upfront costs of recycling glass; and the long-term costs of recycling glass.

While economics are important, we also need to consider a solution that is environmentally sound. Environmental sustainability is a fundamental reason for recycling programs to exist, so we must aim to establish a solution which ensures that glass is effectively recycled. Key parameters related to sustainable glass recycling are as follows: the energy consumption associated with transporting, sorting, cleaning, and reprocessing recycled glass; and the carbon emissions associated with these processes.

Lastly, it is critical that the solution selected for glass recycling at TCSWD is practical and achievable in its context. Glass recycling is only effective so long as there is a reasonable level of efficiency and incentive within each step of the process. For example, residents must be willing and able to recycle their glass in order for the glass to make it through any other step in the process. Key parameters related to practical glass recycling include: the percentage of waste glass that is effectively reused or recycled, the usability of the end product, and the relationship between supply and demand of the end product.

IV. Task at Hand

Our team was provided with four alternative solutions for handling glass at TCSWD:

1) Continue operations using a single-stream recycling model
2) Collect glass separate from other recyclable materials (separate-stream) and send it directly to a glass recycler
3) Purchase a glass pulverizer for producing pulverized glass aggregate (PGA) onsite (requires sorted glass)
4) Stop accepting glass in the recycling program and send it to a landfill

Continuing the use of a single-stream recycling model would mean no change in Tippecanoe's recycling program. Glass would continue to be collected mixed in with other recyclables and sent to the MRF in Indy. Collecting glass separate from other recyclable materials would entail that glass be collected in its own bin at each drop-off location. The glass would then be hauled to a glass-recycler in Indy, skipping the MRF process, where it could generate revenue for TCSWD. Purchasing a glass pulverizer for the onsite production of PGA would remove the entire glass recycling process. Instead, the glass would be reused as aggregate or fill in local construction projects. This could potentially generate revenue for TCSWD. Removing glass from the list of accepted recyclable materials would entail the glass being sent to a landfill with no reuse or recycling applications.

In order to compare these alternatives, our team decided to conduct cost and environmental impact analyses to guide our recommendations on the best plan of action for TCSWD.

V. Methods for Analysis: Economic and Environmental

a. Economic Analysis

In order to do the economic and environmental analyses, we must first determine how much glass is being recycled. From the resources provided by Solid Waste District employee Amy Krzton-Presson which can be found in Appendix B (Table 1), Tippecanoe County receives on average about 668.6 tons of recyclables per month in 2020. However, this includes recycling from Purdue University, Lafayette and West Lafayette curbside pickup, and TCSWD's drop-off bins. This is important because our client only has control over the material from the drop-off bins, and has no say over how the two cities' curbside pickup program or Purdue handles recycling. Amy Krzton-Presson specifically requested that we only look at the glass coming from TCSWD drop-off bins. The reason is that communication between the county and the cities and Purdue over what recyclable material, mainly which types of plastic, the transfer station accepts has been poor, so there is no guarantee that the cities or Purdue will follow the recycling district's example. Because of this and the client's requests, we will only be looking at glass coming from TCSWD drop-off bins. We calculated the amount of glass by removing known pre-sorted tonnage of paper and carboard from the total tonnage from TCSWD, then multiplied the mixed recyclable tonnage by 8%. This number was provided by our client and came from a previous senior design project where they conducted audits of drop-off bins and determined that 8% by mass of the materials in the bins were glass. This results in an average of 13.6 tons per month of glass (Table 1).

The pricing structure to haul the material is complicated. The county pays for all materials, that being 668.6 tons that comes from TCSWD drop-off bins, the two cities, and Purdue, which is shipped from the transfer station by Bestway hauling company to the Republic Services MRF in Indianapolis. TCSWD gets billed $350 per load hauled to the MRF, which is on a per volume basis, and is charged an additional $75 per ton for each ton over 500 tons per month (3). Since glass has a high density and low volume, we are assuming it has a negligible effect on the volume, meaning we will only focus on the mass impact on cost. Since the county consistently goes over the 500-ton limit, we will be using the $75/ton to determine the cost for the 13.6 monthly tons of glass, which is $1075.44 per month, or 254.44/week (Table 1).

To find the best option economically, we will do a cost comparison. This means for each of our four options, we will determine the upfront costs, running costs, savings from switching, and potential revenue sources. The boundaries for the economic analysis are focused solely on the costs/savings to TCSWD. Employee salaries are not included. We will look at a 10-year timeframe to see which option is the best from an economic perspective.

b. Environmental Analysis

While it is important to perform an economic analysis to determine where costs can be saved, it is also important to study which forms of glass recycling carry the least environmental impact. In order to look at the environmental impacts of the four variations of glass recycling, we researched LCAs on the different types of glass recycling. A life cycle assessment (LCA) is the factual analysis of a product's entire life cycle in terms of definable parameters. Every part of a product's life cycle – extraction of materials from the environment, the production of the product, the use phase, and what happens to the product after it is no longer used – can have an impact on the environment in many ways. With LCA, you can evaluate the environmental impacts of a system from the beginning to the end. (14)

For our project, we decided to specifically look at the CO_2 and energy inputs/outputs during the life cycle of glass. While there are other environmental consequences with glass production including water pollution, noise pollution, and habitat destruction, we determined that the energy and CO_2 impacts of glass recycling are the most important. (15)

In terms of the scope of CO_2 analysis, we decided to primarily focus on CO2 emissions involved in production of glass containers and transportation involved with glass collection to recycling centers. We decided to focus on these two variables as their values are going to allow us to properly compare the advantages/disadvantages between the four methods of recycling glass. The same applies for our energy analysis. Glass production and manufacturing requires highly intensive energy usage. The major inputs for the production of glass containers from raw material come from the melting and annealing, forming, and raw material mining and processing. Melting is the most energy intensive process as large quantities are heated up at 2,400 – 2,900 F.

The total energy consumed in the US for the production of glass accounting for melting, annealing, and forming with no postconsumer recycling is 14.5 x 10^6 Btu of primary energy. Primary energy refers to the direct process-energy use by the industry plus fuel and raw-material transportation and production energies (24). In contrast, cullet reduces the energy needed for melting as it melts in a much lower temperature as compared to a batch of virgin material. Therefore, if less energy is required at the plant for melting, less combustion gases released and less CO2 emissions.

If the US recycles 100% of its glass containers i.e., maximum recycling, the primary energy used will be less. This is because cullet will be accounted in the input back to manufacture glass plant which requires less energy to melt than completely virgin material. Energy costs drop about 2-3% for every 10% cullet used in the manufacturing process. The primary energy used is 12.4 x 106 Btu. However, this processing-fuel savings could be offset by energy due additional transportation during collection. (24) Energy due to transportation plays a major role in primary energy used as it could offset some of the energy from fuel processing for glass recycling. As mentioned before, recycling glass containers lessens the demand for energy. Energy costs drop about 2-3% for every 10% cullet used in the manufacturing process. For CO2 emissions, every six tons of recycled container glass used, a ton of carbon dioxide, a greenhouse gas, is reduced. A relative 10% increase in cullet reduces particulates by 8%, nitrogen oxide by 4%, and sulfur oxides by 10%. (28)

In quantifying transportation energy for the US, Gaines and Mintz (1994) have found that the contribution of transportation is 0.39 x 106 Btu/ton of glass containers for maximum new materials (100% of virgin material for manufacturing glass), 0.73 x 106 Btu/ton for maximum recycling (100% return of glass containers for manufacturing glass), and 0.49 x 106 Btu/ton for the mix of new and recycled materials currently used. (24)

Calculating the total energy required to produce one ton of glass containers, process and transportation energies will be added and conversion efficiencies for fuel production and electricity generation will be accounted for as well. The primary energy consumption totals are 17.0 x 106 Btu/ton of bottles with no postconsumer recycling, 14.8 x 106 Btu/ton with maximum recycling, and 15.9 x 106 Btu/ton for the current mix of recycling. It can be observed that for maximum recycling, the primary energy usage decreases by only about 13%. If the quality of glass decreases as the amount of recycling increases, then this small percentage of energy savings could be offset. (24) It is important to note that this values for primary energy have been determined using data available on glass recycling from 1991, it is possible that primary energy savings from current glass recycling methods have increased due to more innovative and sustainable technology.

By comparing the inputs and outputs between the four methods, we may suggest an alternative that is the least environmentally demanding. Overall, the boundaries for the environmental analysis are focused on reducing the total environmental impacts.

VI. Option 1: Status Quo, Single-Stream Recycling

a. Economic Analysis

For the economic analysis of single stream recycling, there is no change from what was previous. The public will continue to put their recyclable glass in the drop-off bins mixed with the other recyclable materials, and the mixed materials will continue to be sent to Indianapolis. This means that they will continue to pay the $1075.44 per month, or $254.44 per week, to recycle the glass. This option requires no investment in new equipment, no education, or cost for changing systems.

b. Environmental Analysis

In terms of CO_2 emissions, keeping the status quo appears to be the most damaging of the three methods of glass recycling. To come to this conclusion, we look at the CO_2 emissions made during transportation. Table 2 shows the total distance travelled from glass collection to recycling facilities. When calculating the CO_2 emissions of the four methods, various assumptions had to be made. Various factors such as road conditions, weight of the recyclables collected, fuel efficiency of each individual trucks are all factors that determine the total output of CO_2. For consistency reasons, we determined a 2.85 kg of CO_2 emission per km travelled (16). With single stream recycling, glass collection trucks would need to travel from curbside pickups to the Tippecanoe County Transfer Station (2770 N 9th St., Lafayette) to a MRF facility in Indianapolis (832 Langsdale Ave., Indianapolis) and finally to a processing facility in Chicago (10330 S Woodlawn Ave., Chicago). However, to keep the starting point the same across all the methods, we decided the starting point should be the Tippecanoe County Transfer Station for all methods of recycling glass (3). SWMD does not have control over curbside pickup, as that is controlled by the two cities and Purdue university and is outside of the scope of the project. SWMD control of the materials begin at the drop off location it controls or for materials from the two cities and Purdue at the transfer station. Therefore, glass collected via single stream recycling would have to travel 407.16 km which would consequently emit 1160.41 kg of CO_2.

Along with CO2 emissions related to transportation, we also need to discuss about the level of CO2 emissions that is reduced due to recycling. Level of CO2 emissions during glass production is enormous due to the virgin materials involved. When producing glass from scratch, virgin materials including soda ash and limestone have to be melted and broken down in furnaces for them to be usable. During this break down in furnaces, decarbonation occurs. The decomposition losses (or decarbonation) occur when a portion of the batch materials is converted into gaseous emissions. For example, limestone decomposes into calcium oxide and CO_2 when heated. To create a ton of glass products, there is about 168 kg of carbon emission due to decarbonation (17). On the other hand, recycling glass undergoes almost no decarbonation. As recycling glass eliminates the need to extract and process raw materials, it bypasses a part of production that releases high levels of CO_2. TCSWD collects approximately 13.6 tons of glass per month. To produce this amount of glass from virgin materials, 2284.8 kg of carbon would be released into the atmosphere due to decarbonation. When glass is broken apart and recycled to produce new glass products, extensive furnace use of melting down virgin materials (e.g., soda ash, limestone) is eliminated.

In terms of energy consumption, the major energy inputs come from production of glass containers from virgin material. The amount of energy used during production and processing of glass varies widely among the different glass manufacturing plants. As a collection of these data is extremely extensive, we will focus mainly on the energy spent during transportation. However, we acknowledge the role energy usage plays during production and therefore look forward to include such data in future reports. As for calculating the energy used during transportation, it will be assumed that a typical collection vehicle is a dump truck using diesel fuel. It also known that the energy intensity of vehicles used in recycling is higher than those used to haul garbage or paper trucks (24).

Additionally, it will be assumed that the parameters for a dump truck will have the following characteristics: run on diesel fuel, engine size of 350 (hp), typical load of 23 (gross tonnage), fuel consumption rate 40 (gal/d), daily mileage of 200 (mi), no of daily trips 1, daily gross tonnage of 23, consumes 5 miles/gallon, produces 241*10E6 Btu per gross ton, and 1206 Btu per ton-mi This characteristic of transportation for a dump truck were taken from Guensler et al. (1991); Wang (1992); and Railroad Facts (1991) in Table 4 (24).

Now that these assumptions for the dump truck have been made, the energy transportation after glass production, usage, and being discarded by consumers can be calculated by multiplying the travelled distance of 407.16 km for single stream recycling uses 305,114.978 Btu per ton-mi of transportation energy.

c. Practical and Social Considerations

By staying with the status quo and continue doing single stream recycling, there will be no change in how people recycle. This means that the county will continue to use an inefficient method but more convenient method to recycle, which has higher rates of contamination and higher chances that the material is landfilled due to the contamination. Since there is no change, the public will continue recycling as they normally do and thus there will be no social change.

VII. Option 2: Separate-Stream Glass Recycling

a. Economic Analysis

For the separate steams recycling, glass will be collected in separate bins at the four drop-off locations around the county. Each bin costs \$3,000, so there will be a total upfront cost of \$12,000. The price of bins was selected from a range of \$1000-5000 for used bins (5). The sorted glass will be still transported to Indianapolis; however, it will go to Strategic Materials. This means that there will be a cost savings of \$254.44 per week by not paying to have the glass travel though the single stream system. Based on the numbers we got from Monroe County (scaled to TCSWD's volume of glass), which operates on a separate-stream glass recycling model, there will be a hauling cost of \$72/week to transport that glass to Strategic Materials. However, since the glass was already separated Monroe County was able to get some revenue from it, and converting it to our system we get a potential revenue of \$95 per week (5). This means in total, there will be an initial investment of \$12,000, however there will be a savings and revenue of \$277.96 each week, with a payback period of 1 year (table 6).

b. Environmental analysis

Compared to single stream recycling, separate stream glass recycling emits lower levels of CO_2 into the atmosphere. Table 2 shows the total distance travelled and the CO_2 emissions made by separate stream glass recycling. With separate stream recycling, glass collection trucks would only need to travel from the Tippecanoe County Transfer Station (2770 N 9th St., Lafayette) to a Strategic Materials in Indianapolis (2503 W Lambert St, Indianapolis, IN 46221) (3). As the travelled distance required is significantly shorter, the total CO_2 emissions of separate stream is also smaller than those of single stream recycling. The total distance travelled by glass via separate stream recycling is 81.27 km which would consequently emit 231.62 kg of CO_2. In terms of CO_2 emissions via transportation, separate stream recycling only emits approximately 20% of single stream recycling.

In terms of energy analysis, the energy from transportation used for separate stream recycling is 60,901.6 Btu per ton-mi for 50.5 km traveled. As compared with single stream recycling, separate stream glass recycling uses 19.96% of the transportation energy used in single stream recycling.

c. Practical and social considerations

All the research on the economic and environmental benefits means nothing if the public does not believe investing in separate stream glass recycling is worth their time and effort. In order to determine whether the public will take the effort to separately recycle their glass containers, we can compare glass collection between single stream and separate stream recycling. For single stream recycling in Tippecanoe County, the average tonnage per month was found to be near 13.6 tons (Table 1). For separate stream recycling in Warren County, the average tonnage per month was found to be near 9.2 tons (Table 3). (5) As the value of glass tonnage collected claims, there is far less glass collected when glass is needed to be separated from other types of recyclables. A part of this may be due to the extra effort required to manually go through and separate the types of disposables instead of disposing them in a single bag. However, it is also important to note the difference in population among the two communities. Population of Warren County is significantly lower than that of Tippecanoe County and may play a role in higher rate of recycling in Warren County. Also, Warren County accepts glass not only from residents but also from local bars and restaurants. This is not the case for Tippecanoe County as Tippecanoe County only collects glass from households. These differences between the two counties may play a role in recycling rates and need to be taken into account.

There are other obstacles with separate stream glass recycling. Traditionally, glass needs to be collected and sorted into different colors in order to be properly remanufactured. Strategic Materials does however collect mixed color glass, but they pay more for glass sorted by color. Additionally, sorted glass is often unclean or mixed with other non-glass entities due to poor recycling practices. (6) Glass that cannot be sorted is broken or mixed during the collection phase along with glass that contains composite materials or contaminants that are not economical or technically impossible to remanufacture. (19) As there are limitations and obstacles to separate stream recycling, it gives more reason for the public to carry out the current method of single stream recycling for its ease of use. However, if separate stream recycling can be managed right, utilizing this method of recycling will most definitely reduce the raw materials required for glass production as well as reduce carbon emissions and energy for production and transportation.

VIII. Option 3: Glass Pulverizer

a. Economic Analysis

For the glass pulverizer, glass will be collected in separate bins at the four drop-off locations around the county. Each bin costs $3,000, so there will be a total cost of $12,000. After it is collected, it will then be pulverized in the pulverizer. The model we are considering is the Compactors Inc Glass Pulverizer Model GP 1500C. This model is capable of processing 1,500 pounds of glass, or 0.75 tons, per hour and has a conveyer belt and a hopper to make loading the glass easier. This means that to process the 13.6 tons each month, it would have to operate at least 18 hours each month. The cost for the pulveriser is $16,990, which makes the total upfront cost $28,990(13). There will be an operating and maintenance cost (part replacement and electricity) of $12.40 per ton of glass, which translates to $42.07 per week (7). This number was obtained from Warren County, which operates a small-scale glass pulverizer (7). From our research we found that the operating cost for a very large-scale glass pulverizer in Santa Fe, NM is $13.26 per ton (20). What this means is operating costs do not fluctuate greatly with size, though for this analysis we will be using the $12.40 per ton as Warren County is closer to the size of our county than the large plant in Santa Fe. There will be a cost savings of $254.44/week by not paying to have the glass hauled to the MRF. In addition, the pulverized glass can potentially be sold. Although we have not found someone who is willing to take the pulverized glass, the Highway department said they are interested and said they pay $9 per ton for fill (22). The issue is that they said that their projects usually run about 3000 tons of fill, far greater than anything we can provide. In addition, we got another quote from Milestone construction saying they pay $7.50 per ton for sand fill, though they mentioned that we would have to verify that with the state that pulverized glass is okay to use in construction (21). They don't have much say in what materials they use, as most of that is controlled by the client or governing bodies. For the analysis, we will be using $7.50 per ton for the revenue for the glass, and be assuming that the buyer will provide transport and haul the pulverized glass. We also are ignoring cost of labor to operate the pulverizes and the electricity cost to run the machine for now. This means that this option will result in an initial cost of $28,990, but a weekly cost savings of $237.81 per week and a payback period of 3 years (table 6).

b. Environmental Analysis

A glass pulverizer is a rather novel technology in the community and some may even be unknown to the benefits it provides. Utilizing a glass pulverizer means that materials can be processed into finer pieces of glass which can be used for a variety of purposes including construction. Having to extract natural aggregates such as crushed stone, gravel, and sand is harmful to the environment as it emits high levels of CO_2 into the atmosphere. Emission factors for crushed stone, and gravel and sand are 0.0032-ton CO2/ton material and 0.0022-ton CO2/ton material, respectively. (26) For 13.6 tons of glass, 0.04 tons of CO_2 can be saved by utilizing pulverized glass than crushed stone. Also, 0.03 tons of CO_2 can be saved by utilizing pulverized glass than gravel and sand. In short, using pulverized glass reduces CO_2 emissions by limiting the amount of natural resource extraction that is required.

In terms of transportation, utilizing a glass pulverizer also provides benefits. When the county decides to invest in a glass pulverizer, it is highly likely that it will be placed at the Tippecanoe County Transfer Station. As a result, collected glass does not need to travel to a MRF facility in order to be recycled. Glass can be directly loaded into the pulverizer once it has been collected in the drop off bins, eliminating the journey to specialized facilities. As no transportation is involved, there are no transportation-related CO_2 emissions or energy consumption.

While a glass pulverizer does not require any travel when located at the Transfer Station, we also need to look at the carbon emissions during operation. How much CO_2 does operating a glass pulverizer emit? To gather these values, we need to learn the specifications of the glass pulverizer that could be used. The glass pulverizer model GP 1500C contains three motors: conveyor motor (0.5 hp), crusher motor (1hp), trommel motor (0.5 hp). A 2hp motor uses 1.49 kWh of electricity. 0.417 kg of CO_2 is emitted per kWh. This means that for 1.49 kWh of electricity, 0.621 kg of CO_2 is emitted. Model GP 1500C can process up to 1500 lbs per hour. In other words, the glass pulverizer can process up to 680 kg of glass per hour. If we were to operate the glass pulverizer to process 13.6 tons of glass, we would need to operate the pulverizer for at least 20 hours. For this amount, 29.8 kWh of electricity is required and 12.43 kg of CO_2 is going to be emitted.

c. Practical and Social Considerations

Utilizing a pulverizer to crush glass on site carries benefits over hauling it off to a MRF or glass recycler. A major benefit is that the crushed glass can be used locally for a variety of applications, namely in construction. Local glass reuse eliminates the need for long-distance transportation to glass recycling facilities. Local use also directly benefits the community which can be promoted to further encourage proper glass recycling.

While the benefits of local glass reuse cannot be ignored, the practical implementation of local crushed glass reuse is quite complicated. Many of its applications, namely in construction, are not well known about. When contacted, both Milestone Contractors and the Tippecanoe Highway Department claimed to know nothing about the applications of PGA in construction. Further, the allowance of PGA in construction applications is dictated by specifications outlined by clients, contractors, and engineers. In terms of state-level construction standards, the Indiana Department of Transportation (INDOT) section 904 addresses standards for aggregates in road-related construction applications. While PGA is not mentioned anywhere in this section, 904.01 details that aggregates shall consist of natural materials or manufactured materials approved by an engineer. This entails that PGA could be used as construction aggregate, given it meets the required specifications for a given application. However, section 904.01 also states that aggregates must be supplied by a Certified Aggregate Producer (CAPP) with the exception of applications in structure backfill. This means that TCSWD would need to undergo testing and approval from the state before it could become CAPP certified and sell aggregates for most applications. This certification process aims to ensure that the product produced is of high quality, consistent quality, and meets the required standards for its intended purpose (27). If TCSWD were to be CAPP certified, approval for the use of PGA would need to be acquired through the engineer in charge of the project in question. Thus, the use of PGA in construction applications is highly dependent upon its familiarity among those in charge of setting aggregate specifications, which varies from project to project. If PGA is to be utilized in local construction projects, there would need to be efforts to educate the construction community about the viability of PGA as an aggregate material.

IX. Option 4: Landfill

a. Economic Analysis

For this option, glass would no longer be accepted at the four drop off locations SWMD runs. This means that instead of recycling the glass, the public would throw away the glass in their trash. This option has a cost saving of $254 per week from not having to haul the glass in the single stream system. The public will be paying in taxes/fees to landfill the glass; however, this is outside the scope of our economic analysis since trash and landfills are not operated by SWMD. There may be additional cost to SWMD in educating and signage to inform the public about the change, however these will be relatively small. Since these are drop off locations, it is not possible to charge people for not complying, but the county can still try to educate the public and put-up signs. This means in total there is no initial investment, and a weekly cost savings of $254.

b. Environmental Analysis

If the county decides that the three methods of recycling glass are not a viable option, the county may instead opt to dispose of their glass products to a nearby landfill located at 2700 North, IN-39, Frankfort, IN. Table 2 describes the total distance glass would travel if this option is selected. From the Tippecanoe County Transfer Station, the glass would travel a total distance of 37.01 km which would emit 105.48 kg of CO_2. In terms of the CO_2 emitted purely via transportation, disposing glass to a nearby landfill may appear to be a palatable option. With 105.48 kg of CO_2 emissions, it is the lowest between both single stream and separate stream recycling. However, there are bigger environmental problems to consider when choosing to dispose of glass containers rather than recycle them.

In terms of energy analysis, the energy from transportation used for disposing landfill is 27734.31 Btu per ton-mi for 37.01 km travelled. When comparing Option 1 and Option 2, we can observe that Option 4, landfill, has the lowest energy usage for energy transportation.

By disposing the collected glass at a landfill, it means that the materials that were used to manufacture the glass cannot be broken down and used again. In other words, virgin materials would need to be extracted and melted down in furnaces in order for glass production. Without utilizing glass cullet, glass would need to be made up of 100% virgin materials. As mentioned before, approximately 168 kg of CO_2 is emitted into the atmosphere for every ton of glass. Not does recycling glass reduce the need for extracting virgin materials, it also saves the energy required to run the furnaces as the demand for virgin materials fall down. Cullet has a lower melting energy than the raw materials as it has been melted previously and there is no endothermal decomposition of carbonates when melting cullet. Cullet can act as a fluxing agent and therefore decreases the melting energy. As a result, it is estimated that 109 kg CO_2 per ton of culet is offset by energy savings (17). These combinations of reducing the demand for virgin materials and increasing energy savings lead to a total CO_2 offset between 318-340 kg CO_2 for each ton of recycled glass used. In other words, utilizing landfills may reduce CO_2 emissions in the short run but bring bigger danger for the future.

c. Practical and Social Considerations

In analyzing the economic and environmental calculations for Option 4, utilizing landfill should presents the most economical savings as the public would throw away their trash and this would be hauled away to a nearby landfill. The cost for this option allows for savings as the glass will not be required to be separated or transported for further sorting.

Environmentally, the traveled distance to the landfill is of 37 km. This results in 105.48 kg of carbon emissions and 27734.32 Btu per ton-mi of energy coming from transportation energy. While the environmental impacts appear to be the least for landfill because we are only considering the distance from the transfer station to the landfill, this is not the case. It is important to consider the long terms environmental impacts after waste has been disposed to a landfill.

The main environmental impacts come from landfill gas and leachate. CO_2 being produced in greatest quantities and CH_4 being the most active are the primary constituents of landfill gas. These gaseous pollutants have significant effects in the surrounding vegetation as lateral migration of the gases through the soil which causes a change of oxygen from the soil and hence a reduction in soil faunal population which causes a decay in vegetation. On the other hand, leachate results in a major problem if there is absence of proper liner systems as it can migrate through the soil and impact nearby bodies of water. (25)

In addition to the environmental impacts, there are also socio-economic and land degradation impacts that need to be considered in the long-term scenario for Option 4. The health effects from contaminants for people living or working near these sites include a higher risk of congenital malformations, birth weight, prematurity and child growth and cancers when in direct contact via inhalation or ingestion of contaminated food and water. (25) Residents may also struggle to adjust to throwing out glass. A significant amount of glass may still make it into the recycling stream, even if it is no longer accepted. This would be practically impossible to fine due to the mixed nature of curbside pickup. Community education would be critical in making the switch to throwing out glass.

X. Discussion

a. Economic Analysis

To compare the four options, we calculated the total amount of money that TCSWD would be required to pay under each option over the next 10 years, which is shown in Figure 2 and Table 3. Looking at the graph and table, it is very clear that the mixed or status quo is the most expensive option. The next most expensive option is the pulverizer, followed by separate steam recycling and landfilling the glass being the lowest. The reason the pulverizer is more expensive over a 10-year span than separate stream recycling or landfilling the glass is due partially to the initial cost being the highest of all options, however what is more important is the operating costs for the pulverizer is far greater than the potential revenue, while both the separate steam and landfill options have revenue greater than cost. With an operating cost at $12.40/ton, the revenue from the pulverized glass would need to be $29 per ton in order to be as economically viable as separate stream recycling or landfilling over ten years. Since the operation cost is higher than the potential revenue estimates we received, this means that the pulverizer would have to rely on the cost savings from not having to transport the glass though single stream recycling to pay it off, which puts it behind both landfill and separate stream recycling, since both have the same cost savings but with a significantly smaller initial cash investment and less operating cost per ton. Even if we assume that there was no operating cost, the revenue from the cullet would need to be at least $17 per ton to make it as good as separate streams recycling or landfilling. Seeing as the highest estimate we got was $9 per ton, it is very unlikely that the pulverizer will be able to be as economically viable as either separate streams or landfilling. Changing the total amount of glass accepted will not have an effect on this, as the weekly values are calculated from $ per ton and thus will not be able to make the revenue higher than the operating cost.

Separate streams are more expensive than landfilling over the short term due to the initial cost investment for the bins, however the increased revenue makes it so that by year 10 sorted recycling is cheaper than landfilling.

Since our cost and revenue is in units of $/ton, this means that scaling it up or down will have no impact on our overall finding. Even if we assume that all the glass from the entire county, including the two cities and Purdue, was under our control, the pulverizer and mixed streams recycling would still be less economically viable as separate stream recycling. The reason why is because for each week of operation, handling the 13.6 tons of glass currently costs $254 per week. Switching to the pulverizer would result in a cash savings of $237.81 per week, while the landfill option has a cash savings of $254 per week and the separate streams would have a cash savings of $277.96 per week (table 6). Because the highest potential revenue of $9 per ton for the glass pulverizer is less than the operating cost of the pulverizer, that being $12.4 per ton, that means that the pulverizer will operate at a loss, no matter how many tons we send though it. This loss cuts into the cost savings from not using mixed recycling, which is why it is less economical then landfilling. Even in the event that the county works with other counties to collectively purchase a pulverizer like in the example in New Mexico to reduce the initial investment, the sole fact that the pulverizer operates at a net loss per ton of glass processed puts it behind landfill and sorted recycling. Also, because sorted recycling potential revenue is higher than the costs, then it is net profitable, which is why even with a higher investment cost over ten years it is better than landfilling the glass.

b. Environmental Analysis

To compare the environmental impacts of the four options, we have decided to calculate the carbon emissions and the energy used from transportation and production for each option. While we are only considering the environmental impacts from the transfer station to its final destination being the recycling facility or the landfill, it is important to note that the biggest environmental impacts come from the production of glass at the plant.

The distance covered for a single stream recycling is 407.16 km and the emissions are 1160.41 kg of CO2 and energy use is 305114 Btu/ton-mi for transportation. For separate stream recycling the distance covered is 81.27, emitting 231.62 kg of CO2 and using 60901.6 Btu/ton-mi of energy for transportation. For the glass pulverizer option, there is no need to transport to the recycling facility or the landfill therefore CO2 emissions and energy used is zero. For the landfill option, the waste has to travel 37 km to the landfill facility. Therefore, the CO2 emitted amounted to 105.5 kg and 27734 Btu/ton-mi of energy from transportation.

Because recycled glass still needs to be melted again to make new glass products, the energy savings from recycling glass are relatively small roughly 10-15%. One ton of recycled glass saves 42 kWh of energy, 0.12 barrels of oil (5 gallons), 714,000 BTU of energy, 7.5 pounds of air pollutants from being released, and 2 cubic yards of landfill space. Over 30% of the raw material used in glass production now comes from recycled glass. Each 10 percent of cullet in the mix reduces the energy required to make new containers by 2 to 3 percent. Using less energy also helps manufacturing equipment like furnaces last longer.

Not only does recycling materials reduce the stress of extracting virgin materials, it also reduces the energy and carbon emitted during the production stages. 10% increase of cullet in furnace reduces CO_2 emissions by 5%. Cullet also replaces natural resources which contain carbon, such as limestone. These materials release CO_2 when they are melted in the furnace while cullet does not. For example, the breakdown of limestone via burning produces up to 0.75 tons of CO_2 per ton of limestone. For every ton of glass recycled, there is also a reduction in raw materials required. For every ton of glass recycled: 1300 lb. of sand, 410 lb. of soda ash, 380 lb. of limestone, and 160 lb. of feldspar is saved. Extracting these raw materials not only leave a huge mark on the environment but also emit high levels of CO_2. For example, 3.13 kg of CO_2 is emitted per ton of limestone extraction. By saving these natural resources, a total of 0.67 tons of CO_2 can be saved per ton of glass. In other words, by replacing 100% of the virgin materials with recycled glass, CO_2 emissions are cut by 58%.

As we can see from Table 2 and Table 5, the option with the highest environmental impact is the single stream recycling as waste has to travel to several facilities in order to be sorted. The option with the least environmental impact is the landfill option. However, this report has not calculated the long-term effects environmental and health effects of landfill gas and leachate which are the major contaminants from disposing waste to landfill.

XI. Recommendations

Our recommendation for how the Tippecanoe County Solid Waste District should proceed with its glass recycling program is dependent on the performance of each of the four proposed alternatives in the economic and environmental analyses along with their practical and social considerations. The parameters discussed in our comparison include upfront and running costs, process embodied energy, and process carbon dioxide emissions. Other factors such as social reception and practical implementation of each of the alternatives were also discussed in the analysis. These parameters and factors are all taken into account when determining the best route for TCSWD to proceed.

For economic sustainability, sorted or separate-stream glass recycling scored the best for minimizing long-term costs, having the lowest combined upfront and running costs after 10 years. Cutting glass out of the recycling program and sending it to a landfill was a very close second in terms of the 10-year cost. The pulverizer option was significantly more expensive than either the landfill or sorted options. While mixed recycling (currently employed by TCSWD) was the cheapest option upfront, it was by far the most expensive option after 10 years.

For environmental sustainability, the best option to reduce emissions by transportation is by using the glass pulverizer, followed by landfill. However, both of these options dispose of the glass and do not recycle it, meaning new virgin material will need to be harvested and turned into glass. This will mean more emissions will come from having to produce new glass, counteracting some of the benefit from the decreased transportation. The most environmentally sustainable option is the separate streams. Although it still has the glass being transported to Indianapolis, by having it already separated it means it doesn't have to then be sent to Chicago, which means that it doesn't burn that extra fuel and release more emissions. In addition, by having it already separated the glass will be less contaminated, which means that more of that glass will be able to be recycled which further reduces the emissions and also reduces the resource demand by not needing as much virgin material to make new glass.

When considering social and practical implications, continuing to accept glass in single-stream recycling would be the easiest to implement since nothing would change at all. Socially, it would be inert since nothing new would provoke any kind of public response. Sending glass to a landfill would be the next easiest option to implement; the only change being in the volume of waste that the landfill takes in and that the transfer station loses. However, there may be a negative public reaction to glass no longer being recycled. Switching to mixed recycling would entail a few inconveniences including purchasing additional bins for the drop-off sites and setting up a new contract for hauling and processing for the separated glass. Additionally, residents would have to be educated on the process of sorting glass apart from their current recycling habits. This could potentially lead to discouragement among recyclers. The pulverizer option would be by far the most difficult to implement. The purchase of a pulverizer and additional bins for separating glass from the normal stream would result in a significant upfront investment. Additionally, the district would need to coordinate with local construction firms/departments to purchase and pick up the crushed glass. Further, local construction entities would need approval from clients or the government to utilize pulverized glass in their projects.

Given the performance of the four alternatives in each of the above categories, our team recommends that the best option for glass recycling at TCSWD, given our current data, is separate stream recycling. It is the most economical option, it is more sustainable than the current method of single stream recycling, and it is similar enough to the current method that the public should not have too much issues switching over.

XII. Suggestions for Additional Research

Of the four options analyzed, the glass pulverizer was by far the most complicated. Pulverized glass is an emerging material aggregate with a large number of potential applications in many industries. Our team focused on its potential for use in road construction applications and found that there is very little knowledge of the material in this industry. There is however plenty of information out there regarding the performance of PGA in a variety of materials such as concrete and asphalt. This information gap between what is available and what the industry is aware of poses difficulties for the use of PGA in construction. Understanding the performance pros and cons of substituting PGA for natural aggregate requires a level of technical knowledge that is beyond the scope of this project. However, this could be a good topic of focus for future senior design teams. Specifically, putting together a document that could be reviewed by project engineers and state regulators could help to improve industry knowledge of utilizing PGA in a variety of applications and could also encourage state regulators to recognize PGA as a potential aggregate source. We also invite future design teams to explore other possible uses for crushed waste glass. These include but are not limited to playground base, beach sand, drainage medium for green infrastructure, and landscaping.

References

Citations:

(1) C&EN. (n.d.). Retrieved March 16, 2021, from https://cen.acs.org/materials/inorganic-chemistry/glass-recycling-US-broken/97/i6

(2) Frequently asked questions: Glass recycling. (n.d.). Retrieved March 16, 2021, from https://lbre.stanford.edu/pssistanford-recycling/frequently-asked-questions/frequently-asked-questions-glass-recycling

(3) A. Krzton-Presson, personal communication, September 2 – March 18, 2020

(4) Kazmeyer, M. (2020, November 17). Energy to recycle glass Bottles Vs. aluminum Cans vs. plastic. Retrieved March 16, 2021, from https://homeguides.sfgate.com/energy-recycle-glass-bottles-vs-aluminum-cans-vs-plastic-79276.html

(5) T. McGlasson, personal communication, October 23, 2020

(6) Chen, H., France, J., Menon, L., & Skipworth, M. (2019). *Characterizing Recycling Contamination and Improving Recycling Practice In Tippecanoe County* (Rep.). West Lafayette, IN.

(7) J. Hobaugh, personal communication, October 7, 2020

(8) Recycling, E. (2012, August 09). Glass Pulverizer. Retrieved December 04, 2020, from https://www.indiegogo.com/projects/glass-pulverizer

(9) D. Hackman, personal communication, November 4-November 7, 2020

(10) A. Krzton-Presson, personal communication, January 28- February 4, 2021

(11) Mohan, A. (2019, February 23). EU glass packaging recycling rate is stable at 74%. Retrieved February 09, 2021, from https://www.packworld.com/issues/sustainability/news/13377021/eu-glass-packaging-recycling-rate-is-stable-at-74#:~:text=The%20latest%20industry%20data%20from,in%20the%20EU28%20of%2074%25.

(12) T. (2020, April 14). Container glass to reduce CO2 by 50%. Retrieved February 09, 2021, from https://feve.org/container-glass-to-reduce-co2/

(13) L.Woodland, personal communication, March 8, 2021

(14) Golsteijn, L. (2021, March 10). LCA basics: Life cycle assessment explained. Retrieved March 15, 2021, from https://pre-sustainability.com/articles/life-cycle-assessment-lca-basics/#h-what-is-a-life-cycle-assessment-lca

(15) Sunrisesanitation. (2018, September 08). Breaking down the environmental impact of glass and plastic: Sunrise sanitation services waste management & recycling company. Retrieved

March 15, 2021, from https://sunrisesanitation.com/breaking-down-the-environmental-impact-of-glass-and-plastic/

(16) Maimoun, M. A., Reinhart, D. R., Gammoh, F. T., & McCauley Bush, P. (2013). Emissions from us waste collection vehicles. *Waste Management*, *33*(5), 1079-1089. doi:10.1016/j.wasman.2012.12.021

(17) Dumitrescu, D. (2019, December 6). Glass recycling, co2 emissions offset. Retrieved March 15, 2021, from https://endofwaste.com/glass-recycling-co2-emissions-offset

(18) Andela, C. (n.d.). Applications for Using Pulverized Glass Aggregate. Retrieved March 15, 2021, from https://www.serdc.org/Resources/Documents/Glass%20Workshop/Andela.pdf

(19) Mohajerani, A., Vajna, J., Cheung, T., Kurmus, H., Arulrajah, A., & Horpibulsuk, S. (2017, September 26). Practical recycling applications of crushed waste glass in construction materials: A review. Retrieved March 15, 2021, from https://www.sciencedirect.com/science/article/pii/S0950061817318068

(20) Local Use of Glass Recycling Guide. (n.d.). Retrieved March 01, 2021, from http://www.recyclenewmexico.com/pdf/Glass%20Guide%202013.pdf

(21) D. Pierce, personal communication, March 5-11, 2021

(22) S. Kline, personal communication, March 8, 2021

(24) Gaines, L. L. and M. M. Mintz. 1994. Energy implications of glass container recycling. Report no. ANL/ESD-18. Argonne National Laboratory, Argonne, IL, USA.

https://digital.library.unt.edu/ark:/67531/metadc1340012/m2/1/high_res_d/10161731.pdf

(25) Danthurebandara, Maheshi & Passel, Steven & Nelen, Dirk & Tielemans, Yves & Van Acker, Karel. (2013). Environmental and socio-economic impacts of landfills.

(26) Smith, Scott H, and Durham, Stephan A. "A Cradle to Gate LCA Framework for Emissions and Energy Reduction in Concrete Pavement Mixture Design." International Journal of Sustainable Built Environment 5.1 (2016): 23-33. Web.

(27) Section 900 – materials details section 901 – pcc ... (n.d.). Retrieved April 7, 2021, from https://www.in.gov/dot/div/contracts/standards/book/sep13/9-2014.pdf

(28) Glass Packaging Institute. Retrieved April 20, 2021, from https://www.gpi.org/why-recycle-glass#:~:text=Unmatched%20Environmental%20Benefits&text=Lessens%20the%20demand%20for%20energy,a%20greenhouse%20gas%2C%20is%20reduced

Appendix A- Figures

Figure 1: Glass Pulverizer

COMPACTORS INC
RECYCLING AND WASTE MANAGEMENT SOLUTIONS

800-423-4003

GLASS PULVERIZER
MODEL GP 1500C

The GP-1500C Glass Pulverizer uses the same proprietary crushing mechanism as the GP-1000 but incorporates a 10" wide feed conveyor and hopper to increase the throughput.

The GP-1500C is an economical solution for low to medium volume glass bottle recyclers. This glass pulverizer is ideal for recycling centers, municipalities, bottlers or any other user requiring -1/8" pulverized glass and -3/8" pulverized glass. The GP-1500C will reduce glass volume by up to 80%. This machine was designed for hard use, trouble free operation and dependability for years of service with throughput rates of up to 1500 lbs per hour.

SPECIFICATIONS

Dimensions: 166" long x 78.5" high x 29" wide | **Conveyor Motor Size**: ½ HP
Crusher Motor Size: 1 HP | **Trommel Motor Size**: ½ HP
Pulverizes glass into two useable sizes (-1/8" and -3/8")
Ideal for any small glass processors, generators or recyclers
Internal trommel screen | Proprietary replaceable crusher blades
Automatically separates labels and trash from ground glass
Rated capacity of up to 1500 lbs. per hour | Mounted on 5" casters for mobility
Start / stop push button stations

-1/8" Glass Sand

-3/8" Glass

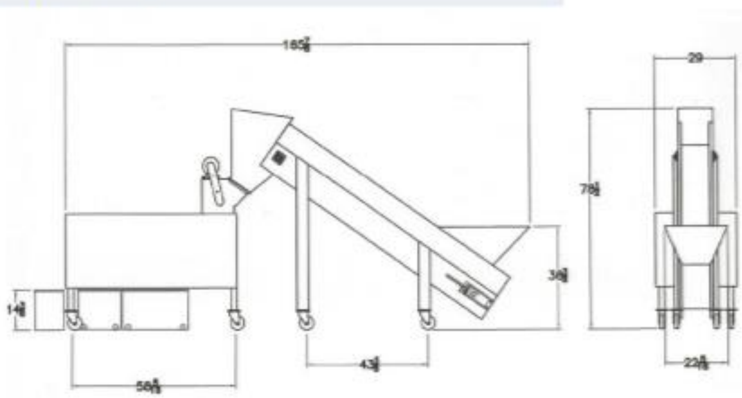
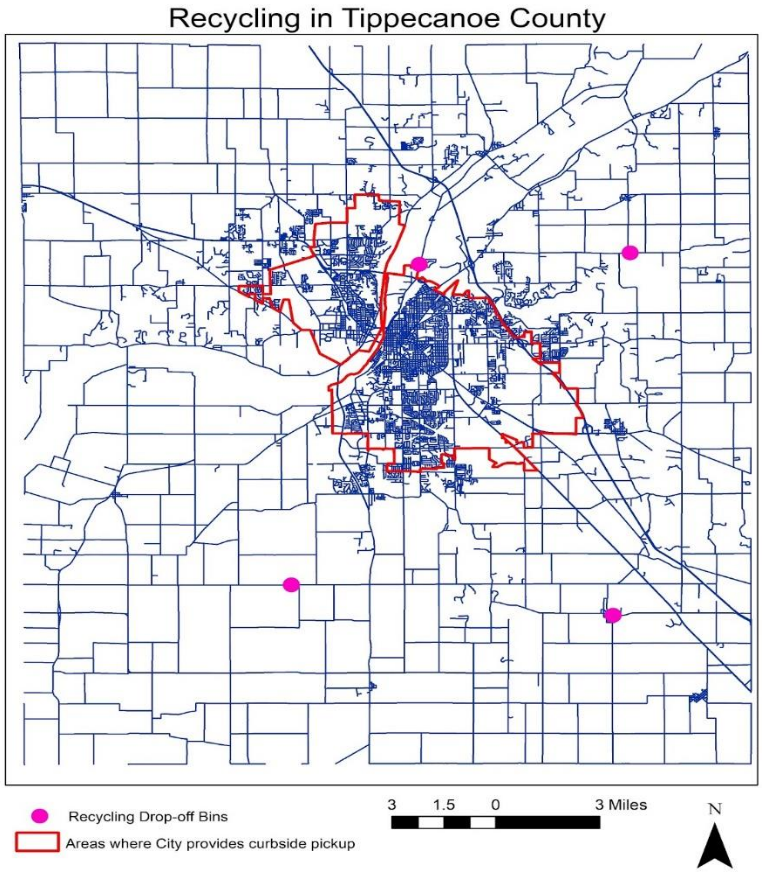


Figure 2: Cost Comparison of the Four Options

Figure 3: Map of where City provides curbside pickup


Recycling in Tippecanoe County
Recycling Drop-off Bins
Areas where City provides curbside pickup
3 1.5 0 3 Miles
N

Appendix B- Tables

Table 1: Calculated Glass Tonnage per Month

Month	Total Tonnage	SWMD(Tons)	Mixed Recycles(ex Paper)(Tons)	Glass(Tons)
January	632.3	202.2	186.5	14.9
February	576.4	169.6	154.1	12.3
March	725.8	178.5	157.9	12.6
April	713.1	200.8	181.8	14.5
May	707.1	191.9	182.5	14.6
June	644.8	216.8	176.9	14.2
July	615.8	188.7	168.8	13.5
August	642.0	160.2	136.2	10.9
September	605.2	169.4	151.1	12.1
October	688.6	194.1	167.3	13.4
November	743.4	207.1	191.2	15.3
December	728.9	211.6	180.6	14.4
Average Tonnage Per Month	668.6	190.9	169.6	13.6

Table 2: Calculated CO2 emissions of recycling glass

	Total distance travelled (km)	Total CO_2 emissions (kg)
Single stream recycling	407.16	1160.41
Separate stream recycling	81.27	231.62
Glass pulverizer	0	0
Landfill	37.01	105.48

Table 3: Cost Comparison of all the Four Options Over 10 Years

Year	Pulverized	Sorted	Mixed	Landfill
0	$28,990.00	$12,000.00	$0	$0
1	$102,910.90	$83,833.37	$86,287.24	$73,056.49
2	$176,831.80	$155,666.74	$172,574.48	$146,112.98
3	$250,752.70	$227,500.10	$258,861.72	$219,169.47
4	$324,673.60	$299,333.47	$345,148.96	$292,225.96
5	$398,594.50	$371,166.84	$431,436.20	$365,282.45
6	$472,515.39	$443,000.21	$517,723.44	$438,338.94
7	$547,857.85	$516,214.98	$605,670.05	$512,800.36
8	$621,778.75	$588,048.35	$691,957.29	$585,856.85
9	$695,699.65	$659,881.72	$778,244.53	$658,913.34
10	$769,620.55	$731,715.09	$864,531.77	$731,969.83

Table 3: Glass tonnage for separate stream glass recycling of Northeast Recycling Center

GLASS TONNAGE		Jan	Feb	Mar	Apr	May	Jun	TOTAL	
Northeast Recycling Center	Clear	3.9	1.45	4.06	4.26	3.86	2.13	19.66	55.24
	Colored	6.51	2.49	6.52	6.09	5.36	8.61	35.58	

Table 4. Characteristics of Transportation Mode Used for Distribution of Recyclables and Nonrecyclables from the MRF

Parameter	**Transfer Truck**	**Dump Truck**
Fuel	Diesel	Diesel
Engine size (hp)	300	350
Typical load (gross tonnage)	13.1	23
Fuel consumption rate (gal/d)	15.4	40
Daily mileage (mi)	80	200
No. of daily trips	2	1
Daily gross tonnage	26.2	23
Miles per gallon	5.2	5
10E6 Btu per gross ton	81	241
Btu per ton-mi	1018	1206
Average length of haul (mi)	40	200
Speed (mi/h)	11.4	25

Sources: Guensler et al. (1991); Wang (1992); and Railroad Facts (1991).

Table 5: Calculated transportation energy usage of recycling glass

	Total distance travelled (km)	**Total distance travelled (mi)**	**Total energy usage from transportation (Btu/ton-mi)**
Single stream recycling	407.16	252.997	305114.978
Separate stream recycling	81.27	50.498837	60901.597
Glass pulverizer	0	0	0
Landfill	37.01	22.996948	27734.319288

Table 6: Payback Period and Weekly Cash Savings

Category	Mixed	Sorted	Pulverizer	Landfill
Years until option matches mixed in cost	0	1	3	0
Cost savings of each option in $/week	($254)	$277.96	$237.81	$254.44

Resumes of Team Members

Alexander Paul

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Education

PURDUE UNIVERSITY — **WEST LAFAYETTE, IN**

Bachelor of Science in Environmental and Ecological Engineering — May 2021
Environmental Policy Minor
Study Abroad-Sustainability Across Sectors, Sweden — GPA: 3.88/4.0

Relevant Experience

Tippecanoe Solid Waste Management District (TSWMD), Lafayette, IN — **August 2020-Present**

Group member

- Communicated with TSWMD and Best Way on current methods of glass recycling and issues they are facing.
- Assessed recycled glass use and possible alternatives in Tippecanoe county.
- Conducted a cost and environmental analysis to provide a recommendation for TSWMD on improvements.

Home With Hope, Lafayette, IN — **January 2020-May 2020**

Group member

- Worked with a Home with Hope through Purdue class to design and install a raingarden to alleviate rainfall runoff.
- Communicated with City of Lafayette Department of Development for plan approval.
- Coordinated with local landscaping company on installation of design and set timeframe for completion.
- Researched potential solutions for parking lot flooding.
- Presented final proposal and created written final report.

Ipswich River Watershed Association, Ipswich, MA — **May 2019-August 2019**

Intern

- Conducted water sampling on lakes testing for dissolved oxygen, turbidity, conductivity, and temperature.
- Analyzed water data, organized samples, and formatted data into excel per MA DEP requirements.
- Completed habitat assessment for herring reintroduction.

The Boxford Trails Association/Boxford Open Land Trust, Boxford, MA — **May-August:2013-2018**

Independent contractor

- Evaluated and maintained over 50 miles of trails in the town of Boxford with minimal oversight to allow Boxford residents to access and enjoy town forests.
- Analyzed the needs and worked under a time constraint.
- Worked with the public and addressed pubic concerns.

Leadership Experience

AQUA-E- *Treasurer* — **September 2019-Present**

- Interacted with Indiana American Water Works Association and Indiana Water Environment Association.
- Assisted in Hosting career panel of 6 water professionals.

Emily Maury Vogel Sophomore Leadership Retreat — **September 2018**

- Reflective retreat to better understand my strengths and leadership styles.
- Learned how to assess the strength of an individual to better lead teams and utilize strengths to accomplish a common goal.

Shreve Club- *Floor Senator* — **September 2017-Spring 2018**

- Elected to represent 86 residents on floor 4 of Shreve Residence hall.
- Voiced residents' opinions on use of organization resources

Society for Environmental and Ecological Engineering (EEE)- *Member* — **September 2017-Present**

- Spoke to prospective EEE students and parents in informational booths.
- Created information on composting for potential Purdue University community service projects
- Attended meetings and interacted with other EEE students.

Technical Skills and Certifications

- Arc GIS Pro; Microsoft Word; Microsoft PowerPoint; Microsoft Excel
- Fundamentals of Engineering Exam(FE)-Anticipated in April 2021

John Lee

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(765) 404-8779 jeonghan0218@gmail.com

Education

- **Purdue University – West Lafayette Campus**
  Environmental and Ecological Engineering
  Class of 2021

Work Experience

- **AutoCAD project at Hartford Club, West Lafayette, IN** *Fall 2017*
  - Created a 3D representation of Lafayette, Indiana for the Hartford Hub (a community center). 3D representation to be used as a display for visitors to have a better visual of Lafayette in birds-eye view
  - Required group members to self-educate on AutoCAD and how to create 3D representation of a community
- **Energy usage analysis of a prospect building, West Lafayette, IN** *Spring 2018*
  - Created a research portfolio for the Hartford Hub about the different types of energy usage for a new apartment they were considering of building.
  - Considered both environmental and the economic impacts of various energy inputs of an apartment building
- **Barista at Starbucks** *July 2019 – June 2020*
  - By working as a barista at Starbucks, I got the opportunity to communicate and work efficiently with multiple people with different backgrounds, something that might be hard to obtain from studying near fellow peers with similar goals and undergraduate degrees.

Community Involvement

- **Disaster Relief Club** *August 2014 – April 2017*
  - General Member and Co-leader of a disaster relief club
  - Raised funds to help people in need globally including people in Kenya regarding water deficiency and the people of the Philippines affected by Typhoon Haiyan.
- **Computer Science Club** *Fall 2016 – Jan 2017*
  - General member of a computer science club that included learning of both C++ and python languages.
  - Gain familiarity with utilizing XCode for creating apps and games.

Research Experience

- **Undergrad Research Assistant** *June 2019 – August 2019*
  - Worked alongside a graduate student and a faculty member in their study of material recovery from smartphones that are discarded.
  - Experienced what typical environmental engineers do in a lab environment.

Nancy Cai Wu

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Objective: A full time position in the field of environmental engineering with an emphasis on health, safety, or energy.

EDUCATION:

Purdue University, West Lafayette, IN **May 2021**
Environmental and Ecological Engineering, Bachelor of Science Major GPA: 3.20/4.0

Certifications:
Six Sigma Foundations, Linkedin Learning Jan 2021

WORK EXPERIENCE:

INSPIRE Research Institute for Pre-College Engineering, Research Assistant (West Lafayette, IN) **Sept 2019 - present**
-Conducted extensive review process on items to determine integration of engineering practices, thinking and design
-Submitted detailed evaluations on items that promote engineering practices to the 2019 - 2020 Purdue Engineering Gift Guide, annual INSPIRE magazine.

Managed Career Solutions, Intake Analyst Intern, (Alhambra, CA) **May 2017 - Aug 2017**
-Formulate and implement plans to reduce unemployment among young adults in the community of Alhambra
-Informed youth from low income families about internal programs to facilitate their accessibility to jobs and internships
-Communicated with unemployed people to align them with their best fit MCS program towards self-sufficiency

Boston-Area Climate Experiment (BACE), Research Assistant (West Lafayette, IN) **Nov 2016 - Aug 2018**
-Classified biomass samples from BACE to identify CO2 and characterize ecosystem responses to climate change
-Inputted biomass data into Excel files and generated graphs and metrics to characterize ecosystem responses

PROJECTS:

International Development Project: Water Supply in the Dominican Republic (West Lafayette, IN) **Aug 2020 - present**
- Implement and improve the installation of water treatment systems and maintenance practices in five rural communities of the Dominican Republic
- Act as a liaison between Dominican partners and the communications team on campus
- Evaluated the course's performance and shared information about class outcomes through posters, presentations, and publications

Ecomake Hackathon, Research Team Lead (West Lafayette, IN) **Oct 2019, Oct 2020**
- Participated twice in a 3-day long engineering design competition centered on sustainability
- Created and designed a prototype on a seed planting mechanism and fertilization robot using AutoCAD and laser cutting
- Presented the ecological initiative among panel of judges

Sustainable Tiny House Project, Cofounder (West Lafayette, IN) **Sept 2017 - Aug 2018**
-Emerging project working on building tiny homes in order to educate the community on sustainable living
-Advocated and incorporated the implementation of a class on building tiny houses

EXTRACURRICULAR ACTIVITIES:

Latinos in Science and Engineering (MAES), Secretary **Aug 2017 - Dec 2018**
-Coordinated MAES events that promoted STEM networking, professionalism, and development for traditionally underrepresented groups

Louis Stokes Alliance for Minority Participation (LSAMP INDIANA), Research Scholar **Aug 2017 - Aug2018**
-Participated and interacted with faculty mentor and graduate students to promote STEM enrichment in minority groups

AWARDS AND HONORS:

Purdue University
Louis Stokes Alliance for Minority Participation Research Scholar Fall 2017
Wayne and Barbara Jennings Memorial Scholarship Recipient Fall 2017 - Spring 2019
J. Kelly and Margaret Ritchey O'Neall Memorial Scholarship Fall 2017 - Spring 2020

SKILLS:

-Language: Spanish (native) -MATLAB, Python, Excel, Word

Mason Danielson

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Current Address: 1134 Northwestern Ave., West Lafayette, IN 47906
Permanent Address: 5008 W. Michael Ln., Bloomington, IN 47404

Education

Senior at Purdue University majoring in Environmental and Ecological Engineering with minor in Philosophy (Graduating Spring 2021)

Experience

- Forestry Work Crew at BSA's Philmont Scout Ranch (Summer 2019)
    - Completed NRCS Log Erosion Barrier (LEB) project in burn scar of 2018 Ute Park Fire
        - Met strict specifications for LEB placement and worksite safety provided by the Natural Resources Conservation Service
        - Completed project on time despite a week of delays due to adverse weather
    - Conducted Timber Stand Improvement (TSI) for fire prevention
        - Operated and maintained a chainsaw for daily use
        - Followed a detailed prescription for determining which trees to remove
        - Used communication and personal judgement to safely remove hazardous trees in areas occupied by other workers and participants
- Glass Recycling Senior Design Team (Fall 2020, Spring 2021)
    - Partnered with Tippecanoe County Solid Waste District (TCSWD) to develop a sustainable solution for the county's glass recycling program
    - Took on the role of team leader and project partner contact
    - Developed a quantitative economic analysis comparing multiple alternatives for glass recycling
    - Working toward creating a pamphlet which provides our findings and recommendations in a readable format that can be utilized by TCSWD and government officials
    - Schedule and conduct periodic meetings with partner; complete progress reports
- Worked at Indiana University Recreational Sports summers of 2015, 2016, 2017, and 2018
    - Lifeguard and Swim Instructor
    - Writing lesson plans, completing shift reports, and filling out incident report forms

Skills/Certifications

- Computer Languages/Programs: MATLAB, C, RStudio, VBA, Mathcad
- Microsoft Office: Excel, Word, Powerpoint
- CAD: Autodesk Inventor Pro, Solidworks CATIA, AutoCAD
- GIS: ArcGIS
- Chainsaw use and maintenance + tree felling experience
- Camping/Backpacking and Outdoorsmanship skills
- Leadership skills and experience

Achievements

Eagle Scout

- Designed and built 2 large storage units for Eagle Project
- Created and managed project budget
- Created a project proposal, project plan, and project report
- Led and managed project to completion